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Reliability of transcutaneous measurement of oxygen and carbon dioxide partial pressure with a combined Po_2-Pco_2 electrochemical sensor in the fetus during labor

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1 Introduction

The synchronous measurement of Po_2 and Pco_2 in the fetus during labor is of special interest for studying the fetal physiology and pathophysiology [1, 5, 6, 7, 10, 13, 17]. Because of the difficulties of application of two skin electrodes on the fetal scalp during labor, a combined electrochemical Po_2-Pco_2 transcutaneous sensor (RADIOMETER PROTOTYPE) was tested in the fetal scalp [15]. In such electrodes, the measuring systems for tc Po_2 and tc Pco_2 are incorporated in one housing [2, 8, 11, 19]. The aim of this study was to analyse the accuracy with which it is possible to measure the Po_2 respectively Pco_2 of the fetal blood by means of such a combined electrode during the application on the fetal scalp. The data measured by the transcutaneous combined electrode were compared with the data of the fetal blood analysis (FBA) respectively blood samples from the umbilical artery (UA) [10,12].

2 Methods

The Radiometer prototype of a combined tc Po_2/tc Pco_2 electrochemical sensor was applied to the fetal scalp in 21 fetuses during labor. Details of this design, which is based on a SEVERINGHAUS design, are reported elsewhere [19]. The housing of the sensor has the same size as the tc Po_2 respectively tc Pco_2 electrode of RADIOMETER. A CLARK type polarographic O_2 electrode and a STOW SEVERINGHAUS CO_2 electrode are incorporated into a single device [4, 18] (Fig. 1). Calibration of the combined electrode was performed with a RADIOMETER calibration gas which consists of 10% CO_2 and

Curriculum vitae

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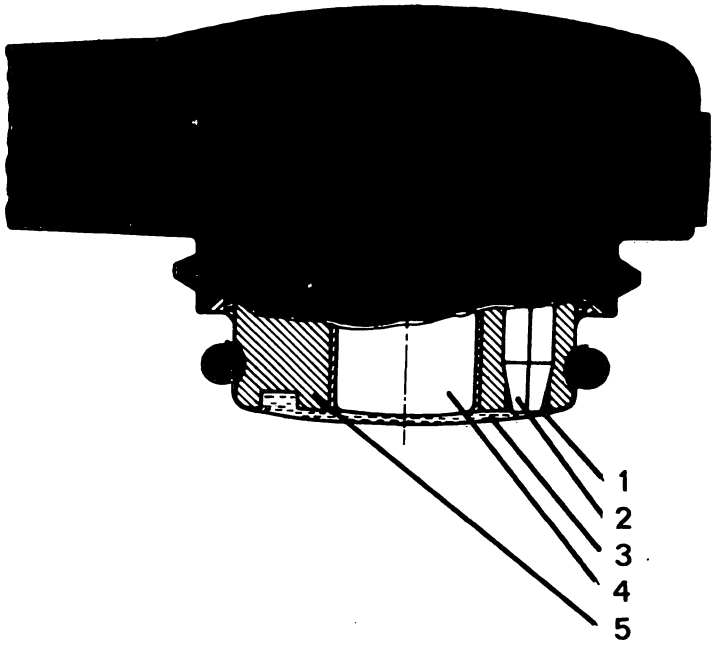

Fig. 1. Schematic drawing of a cross-section of the electrochemical sensor for combined measurement of tc Po_2 and tc Pco_2 (RADIOMETER Prototype). 1. Membrane system, 2. platinum cathode, 3. electrolyte, 4. pH-electrode, 5. silver chloride reference.

15% O_2 at 44 °C. No temperature compensation or metabolism offset was used. To elicit the electrode drift during the measuring procedure controls were performed at the end of the measurement using the calibration gas. The maximal drift during our study was 8% for CO_2 (after a measuring period of 3 hours and 21 minutes) and 5% for O_2 (after a measuring period of 1 hour and 54 minutes). Skin readings were corrected for the drift found by the post skin measurement — assuming a linear drift of the electrode.

The electrode was fixed onto the fetal scalp with a tissue adhesive 2-butylcyanoacrylate. After the application the measuring chamber was filled with contact solution by means of a tube system bored into the fixation ring of the electrode [16]. The steady-state for tc Pco_2 was reached in 15.4 ± 3.5 SD, for tc Po_2 10.3 ± 2.5 SD minutes. Of 24 attempts made, the application was unsuccessful in 3 cases, when the electrode was dislodged during retraction of the fetal blood sampling tube. For synoptic coverage of the results of the measurements, the tc Po_2, the tc Pco_2 and the relative heat deviation of the combined electrode as well as the cardiotocogram were traced polygraphically on a multichannel recorder. Blood gas analysis of the fetal blood samples (FBA) respectively the umbilical artery (UA) were performed on a RADIOMETER ABL 3 blood analyser. The linear correlation coefficient, the slope, the intercept and the significance were calculated for comparison of transcutaneous Pco_2 levels respectively Po_2 levels to the blood levels (FBA and UA).

Additionally the ratio of tc Pco_2 and blood Pco_2 respectively tc Po_2 and blood Po_2 were calculated in order to present the mean and standard deviation (SD) of this ratio.

We studied 21 fetuses during labor. The total duration of evaluation was 61 hours and 30 minutes. The average individual evaluation time was 176 minutes (range from 36 minutes to 6 hours and 21 minutes). All fetuses had vertex presentation. All newborns were vigorous (Apgar ≥ 7); in 5 fetuses the pH-level of the blood samples from the umbilical artery was between 7.24 and 7.20, in one fetus 7.18. Eleven babies were born spontaneously; six by vacuum extraction; three by means of spoons (modified forceps) [14], and 1 by cesarean section. Thirteen mothers were para-I, eight were para-II, four multipara. Informed consent was approved in all cases.

3 Results

Using a multichannel recorder we succeeded in achieving polygraphic tracings of the uterine contractions (labor), the fetal heart rate (FHR), the relative heat deviation of the combined electrode and the transcutaneous partial pressure of oxygen (tc Po_2) and carbon dioxide (tc Pco_2) (Fig. 2). Transcutaneous values were compared with values of synchroneously collected blood samples. For the transcutaneous Pco_2 we found a statistically significant correlation, for the comparison of both the FBA ($r = 0.95$, intercept $= -22.94$, slope 1.95, $p < 0{,}001$) (Fig. 3). The mean ratio of tc Pco_2 and Pco_2 of the FBA for each point was 1.43 ± 0.15 SD.

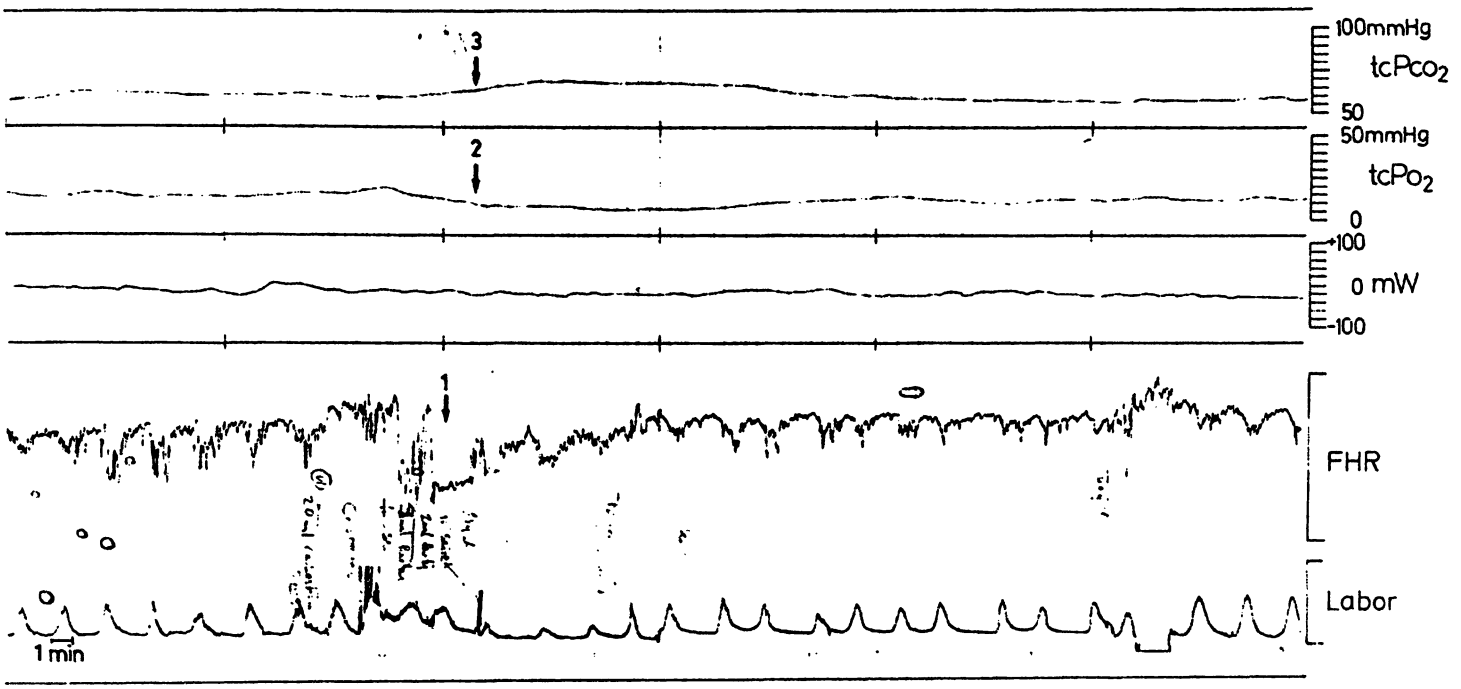

Fig. 2. Example of a combined Po_2-Pco_2 measurement in the fetus during labor: polygraphic tracing of the labor (intrauterine pressure — range: 0—100 mm Hg, fetal heart rate — FHR range: 0—200 beats/min, relative heat deviation of the electrode, range ± 100 mW, the transcutaneous partial pressure of oxygen (tc Po_2) range: 0—50 mm Hg and the transcutaneous partial pressure of carbon dioxide (tc Pco_2) range: 50—100 mm Hg.

Comparing the transcutaneously recorded Pco_2 of the moment of delivery with the Pco_2 value measured in blood samples of the umbilical artery (UA) we also found a statistically significant correlation ($r = 0.75$, intercept $= 0.30$, slope $= 1.45$, $p < 0.05$ (Fig. 3). The mean ratio of tc Pco_2 and Pco_2 of the UA for each point was 1.46 ± 0.17 SD.

Comparing the data of the transcutaneous Po_2 monitoring with the fetal blood analysis, we found a statistically significant correlation ($r = 0.83$, intercept $= -4.97$, slope $= 1.23$, $p < 0.001$) (Fig. 4). The mean ratio of each point of this comparison was 0.93 ± 0.22 SD.

When analysing the data of the tc Po_2 monitoring with the umbilical artery values (UA), we did not find a statistically significant correlation ($r = 0.36$, intercept $= 0.94$, slope $= 0.54$, $p > 0.05$). When the recording was performed up to the expulsion of the baby, the Po_2 value of the transcutaneous measurement was in some cases much lower than the values of the umbilical artery (Fig. 4). The mean ratio of tc Po_2 and Po_2 of the UA for each point was 0.64 ± 0.32 SD.

4 Discussion

We performed a study of a new combined Po_2-Pco_2 electrochemical sensor in an application where it might be particularly useful. The simultaneously performed measurement of O_2 and CO_2 is of special interest for studying the physiology and pathophysiology of the fetus during labor. Such simultaneous transcutaneous estimation of Po_2 and Pco_2 has been performed by mass spectrometry with a single sensor [3, 11]. Compared with this method which is judged to be cumbersome by some authors, the use of electrochemical sensors is more convenient [20].

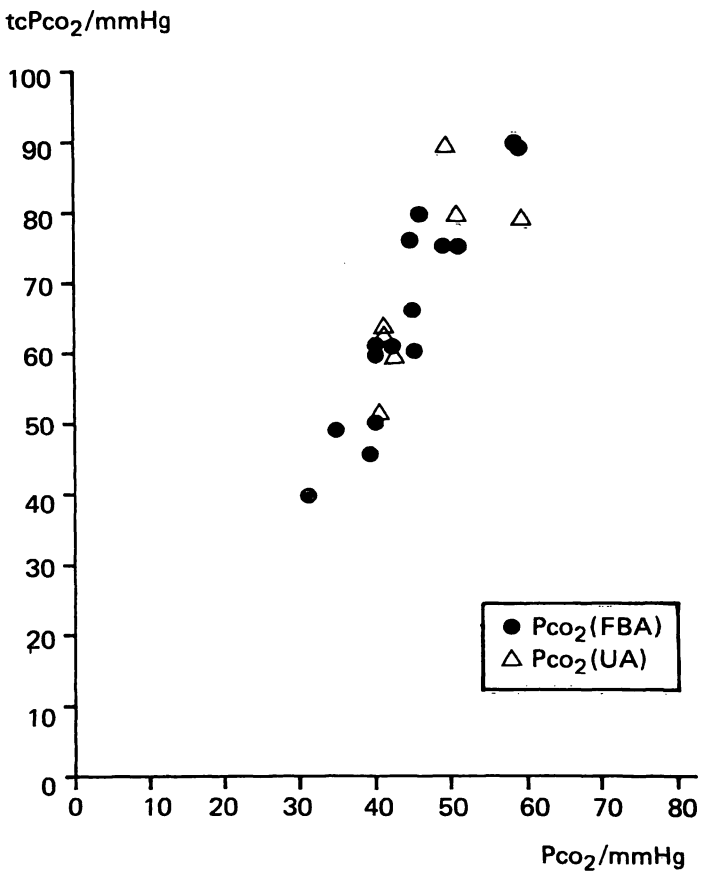

Fig. 3. Correlation between the tc Pco_2 and the Pco_2 of the fetal blood analysis (FBA) ($r = 0.95$, intercept $= -22.94$, slope $= 1.95$, $p \leq 0.001$), respectively measured in samples of umbilical artery (UA) blood ($r = 0.75$, intercept $= 0.30$, slope $= 1.45$, $p \leq 0.05$).

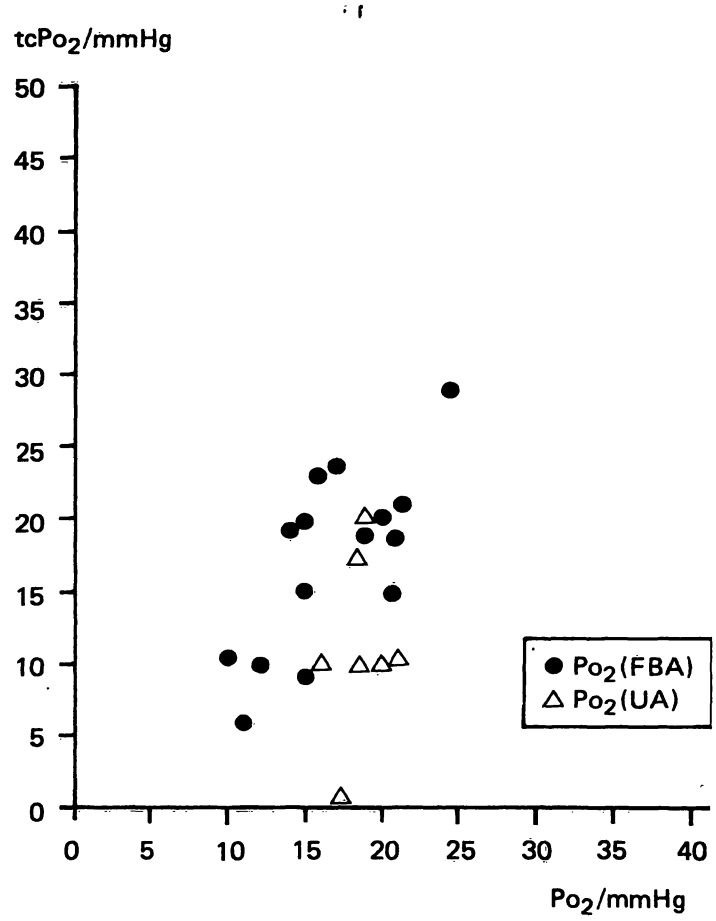

Fig. 4. Correlation between transcutaneous Po_2 (tc Po_2) and Po_2 of fetal blood analysis (FBA) ($r = 0.83$, intercept $= -4.97$, slope $= 1.23$, $p < 0.001$), respectively measured in umbilical artery (UA) blood ($r = 0.36$, intercept $= 0.94$, slope $= 0.54$, $p > 0.05$).

Up to now this had been possible only by the use of two spearate electrochemical electrodes for tc Po_2 and tc Pco_2 measurements [6, 9, 15]. Such application of two electrodes on the fetal scalp during labor is difficult [15]. The fact that the success of the application of two electrodes was considerably lower than the success achieved with the use of one single transcutaneous electrode implicates that it is desirable to have a combined electrode, which would make the application much easier. Because of the difficulties connected with the application of two skin electrodes on the fetus during labor, the development of an electrochemical sensor which measures tc Po_2 and tc Pco_2 simultaneously is of interest especially for this application in perinatal medicine [15].

Of major concern was the fact that as a result of polarographic O_2-reduction at the cathode, OH^- ions are produced, leading to an erroneous Pco_2 change [8]. In the SEVERINGHAUS design this effect is compensated by stoichiometrical consumption of OH^-ions [19]. The rates of drift were predicted to be acceptably small [8, 19, 20]. WHITEHEAD et al. as well as HUCH et al. reported that it is possible to estimate PaO_2 and $PaCO_2$ transcutaneously in infants with a single electrochemical sensor [8, 20].

Our experience with the RADIOMETER combined electrode proved that using a single sensor was much more convenient compared with the use of two electrodes. A dislodging of the electrode during the retraction of the fetal blood sampling tube was a little more likely with the combined Po_2-Pco_2 electrode compared with the tc Po_2, respectively tc Pco_2 single electrodes, due to the fact that the cable of the RADIOMETER

combined electrode is much stiffer. A future modification should lead to a success rate comparable to single electrodes, which is reported to be about 90% [7].

During our study the measurement of the tc Po_2 and tc Pco_2 proved to be reasonably reliable in measuring the blood gas values. For the partial pressure of carbon dioxide there was a statistically significant correlation when compared with the values of fetal blood.

By the comparison of the transcutaneous Pco_2 values with Pco_2 values of the FBA we found that the tc Pco_2 exceeds the blood gas level of carbon dioxide considerably; this is known to be due to a raised temperature and the CO_2 production of the tissue [18]. The regression slope calculated by us is misleadingly high due to the zero offset (Fig. 3). While there is an intercept of -22.94 we know that at zero the electrode reading would still be above and not below that point.

Here it was of interest to calculate the mean ratio of tc Pco_2 and blood Pco_2 for each point as additional information may be achieved in this way. The reason for this is that the regression is not determined by deliberate variation of Pco_2 in the subjects, so little evidence is accumulated relating to the actual slope of the electrode response. The mean ratios for tc Pco_2 and Pco_2 of the FBA respectively the UA are 1.43 respectively 1.46.

During our measurements with the combined tc Po_2-tc Pco_2 electrode in the fetus, the values of tc Po_2 were less consistent — in measuring the Po_2 of the fetal blood, the tc Po_2 level tended to underestimate the sanguinous level. Such findings have been reported by other authors using single tc Po_2 electrodes. In this context LÜBBERS has pointed out that the tc Po_2 (and tc Pco_2) is not only dependent on the blood gas values but also on the local blood flow. When the Po_2 in blood is known, the ratio tc Po_2/Po_2 (the so-called "tc Po_2 index") can be used to describe the state of circulation [7]. For the comparison of the tc Po_2 with the Po_2 of the samples from the umbilical artery (UA), we found a low mean ratio (0.64).

This might be interpreted as a sign of decreased local blood flow during the expulsion of the babies. The Pco_2 measurement seems to be much less influenced by the progress of labor as compared with the tc Po_2 measurement. This finding consists with the experience with single transcutaneous electrodes for Po_2 respectively Pco_2 measurement [6, 9, 17].

Taking into consideration the mechanisms and the extent by which transcutaneous values are influenced, the continuous recording of the partial pressure of both oxygen and carbon dioxide by means of a combined Po_2-Pco_2 electrochemical sensor will hopefully lead to an improved understanding of the fetal physiology and pathophysiology.

Summary

A combined single electrochemical sensor designed to measure synchronously and transcutaneously oxygen partial pressure and carbon dioxide partial pressure (RADIOMETER prototype) was applied onto the scalp in 21 fetuses during labor. The values of tc Po_2 respectively tc Pco_2 were compared with the values of fetal blood analysis (FBA) and blood from the umbilical artery (UA): **Comparing the tc Pco_2 with the values of the FBA we found the values to be very consistent ($r = 0.95$, $p < 0.001$).** For the comparison of the tc Pco_2 with the values of the umbilical artery, the correlation coefficient was lower ($r = 0.76$, $p < 0.05$). The transcutaneous measurement of Po_2 as compared with the values of the fetal blood analysis was also quite accurate ($r = 0.83$, $p < 0.001$).

Looking at the values of the transcutaneous measurement during the expulsion of the fetus and its comparison with the values of the umbilical artery, it was an interesting finding, that **values of the transcutaneous estimation of Po_2 were much lower in some cases and no statistical correlation was found ($p > 0.05$).** We conclude that the combined electrochemical sensor for measuring tc Pco_2 and tc Po_2 is a new additional tool for studying the physiology and pathophysiology of the fetus during labor, but as the accuracy of Po_2 and Pco_2 in the fetal blood is influenced by the progress of labor, the special characteristic of the transcutaneous measurement has to be taken into account when values are interpreted.

Keywords: Combined Po_2-Pco_2 sensor, fetal monitoring, transcutaneous blood gas measurement.

Zusammenfassung

Transkutane Messung von fetalem Po_2 und Pco_2 mit einer Kombinationselectrode

Bei 21 Feten sub partu haben wir eine elektrochemische tc Po_2-tc Pco_2-Kombinationselektrode (RADIOMETER Prototyp) eingesetzt. Die Zuverlässigkeit der transkutan erhobenen Meßdaten wurde durch den Vergleich mit dem Po_2 bzw. Pco_2 des fetalen Blutes überprüft. Für den tc Pco_2 fanden wir eine gute Überstimmung mit den Daten der Fetalblutanalyse (FBA) ($r = 0{,}95$, $p < 0{,}001$). Bei dem Vergleich zwischen den tc Pco_2-Werten mit den Pco_2-Werten aus der A. umbilicalis fanden wir einen niedrigeren Korrelationskoeffizienten ($r = 0{,}76$, $p < 0{,}05$). Die tc Po_2-Messung stimmte mit den Daten der FBA gut überein ($r = 0{,}83$, $p < 0{,}001$), die tc Po_2-Werte lagen jedoch zum Teil deutlich unterhalb von Po_2-Werten aus der UA. Hier fanden wir keine statistisch signifikante Korrelation ($p > 0{,}05$).

Wir stellen fest, daß die untersuchte tc Po_2-tc Pco_2 Elektrode ein geeignetes Instrument zum Studium der Physiologie und Pathophysiologie des Feten darstellt.

Der Einfluß des Geburtsfortschrittes auf die Zuverlässigkeit der transkutanen Meßdaten muß jedoch bei der Interpretation der Ergebnisse berücksichtigt werden.

Schlüsselwörter: Fetale Überwachung, Po_2-Pco_2 Kombinationselektrode, transkutane Blutgasmessung.

Résumé

Fiabilité de la mesure transcutanée de la pression partielle d'oxygène et de dioxyde de carbone à l'aide d'un capteur électrochimique mixte Po_2 et Pco_2 chez le fœtus au cours du travail

On a appliqué sur le scalp de 22 fœtus au cours de travail un unique capteur électrochimique mixte destiné à mesurer de façon synchrone et en transcutanée la pression partielle d'oxygène et de dioxyde de carbone (prototype RADIOMETER).

On a comparé respectivement les valeurs de la tc Po_2 et de la tc Pco_2 avec les valeurs de l'analyse du sang fœtal (SF) et du sang de l'artère ombilicale (AO). En comparant les valeurs de la tc Po_2 avec les valeurs du SF, nous trouvons des résultats compatibles ($r = 0{,}95$; $p < 0{,}001$). Le coefficient de corrélation est plus bas ($r = 0{,}76$; $p < 0{,}05$) pour la comparaison de la Pco_2 avec les valeurs de l'artère ombilicale. La détermination transcutanée de la Po_2 comparée avec les valeurs analysées dans le sang fœtal est également tout à fait faible ($r = 0{,}83$; $p < 0{,}001$).

En regardant les valeurs de la mesure transcutanée au cours de l'expulsion et en les comparant avec les valeurs de l'artère ombilicale, on trouve une donnée intéressante: les valeurs de l'estimation transcutanée de la Po_2 sont plus basses dans certains cas et aucune corrélation statistique n'a été trouve ($p < 0{,}05$).

Nous concluons que le capteur électrochimique mixte pour la mesure de la tc Pco_2 et tc Po_2 est un outil nouveau supplémentaire pour étudier la physiologie et la physiopathologie du fœtus au cours du travail, mais comme l'exactitude de la Pco_2 et de la Pco_2 dans le sang fœtal est influencée par l'évolution du travail, les caractéristiques spéciales de la mesure transcutanée doivent être prises en compte dans l'interprétation des résultats.

Mots-clés: Capteur mixte Po_2-Pco_2, mesure transcutanée des gaz sanguins, surveillance fœtale.

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Springer Pediatrics

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Editors: **H.-J. Bandmann, R. Breit,** Munich
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1984. 82 figures, 77 tables. XIV, 229 pages
Soft cover DM 89,–. ISBN 3-540-13267-8

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Child Abuse

Editors: **A. Carmi,** Haifa; **H. Zimrin,** Tel Aviv

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This interdisciplinary work shows that child abuse is not the result of uniform behavior patterns, but rather has many causes requiring many different types of treatment. The contributions focus on legal, pathologic, sexual, psychiatric, and familial aspects of the problem.

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